Estimating and projecting COVID-19 Mortality Impact in Asia

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Agenda

1. Background
2. Pre-pandemic mortality trend
3. Mortality trend during pandemic
4. Excess mortality in pandemic
5. Long-term mortality impact
6. Implications, recommendations and limitations
7. Stochastic mortality models
   - Lee-Carter model
   - Two-parameter-level model
   - Parameter estimation
   - Monte Carlo simulation
   - R code and tables

Background

Motivation

Focus on Asia

- Study all-cause mortality experience of general population in 5 Asian countries

Forward-looking view

- Forecast future mortality based on long-term trend and COVID-19 mortality impact

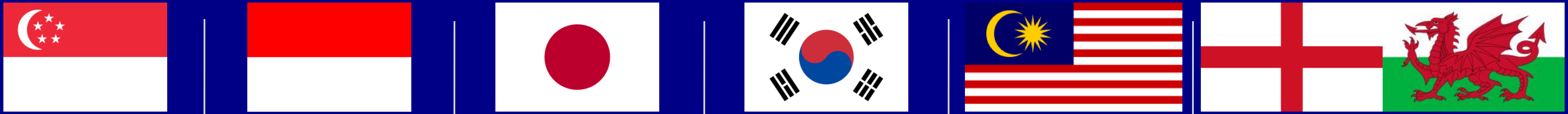
Actuarial context

- Evaluate impact relevant to life insurers and policymakers

Tool and inspiration

- Findings to serve as inspiration and models to serve as tool for insurers and policymakers to evaluate own impact

Country (region) considered



Singapore | Indonesia | Japan | South Korea | Malaysia | England & Wales

- General population mortality data in these countries/regions since 1970s/1980s
- Singapore, Japan, Korea, England & Wales: 2020 – 2022 pandemic data
- Malaysia: 2020 – 2021 pandemic data
- Indonesia: 2020 pandemic data
- England & Wales included for comparison purpose

Statistics for describing mortality risk

Age-standardized mortality rate

- A blended mortality rate of a population based on a pre-defined age mix
- Allows for comparison of overall mortality rate without noise from age mix

Period life expectancy

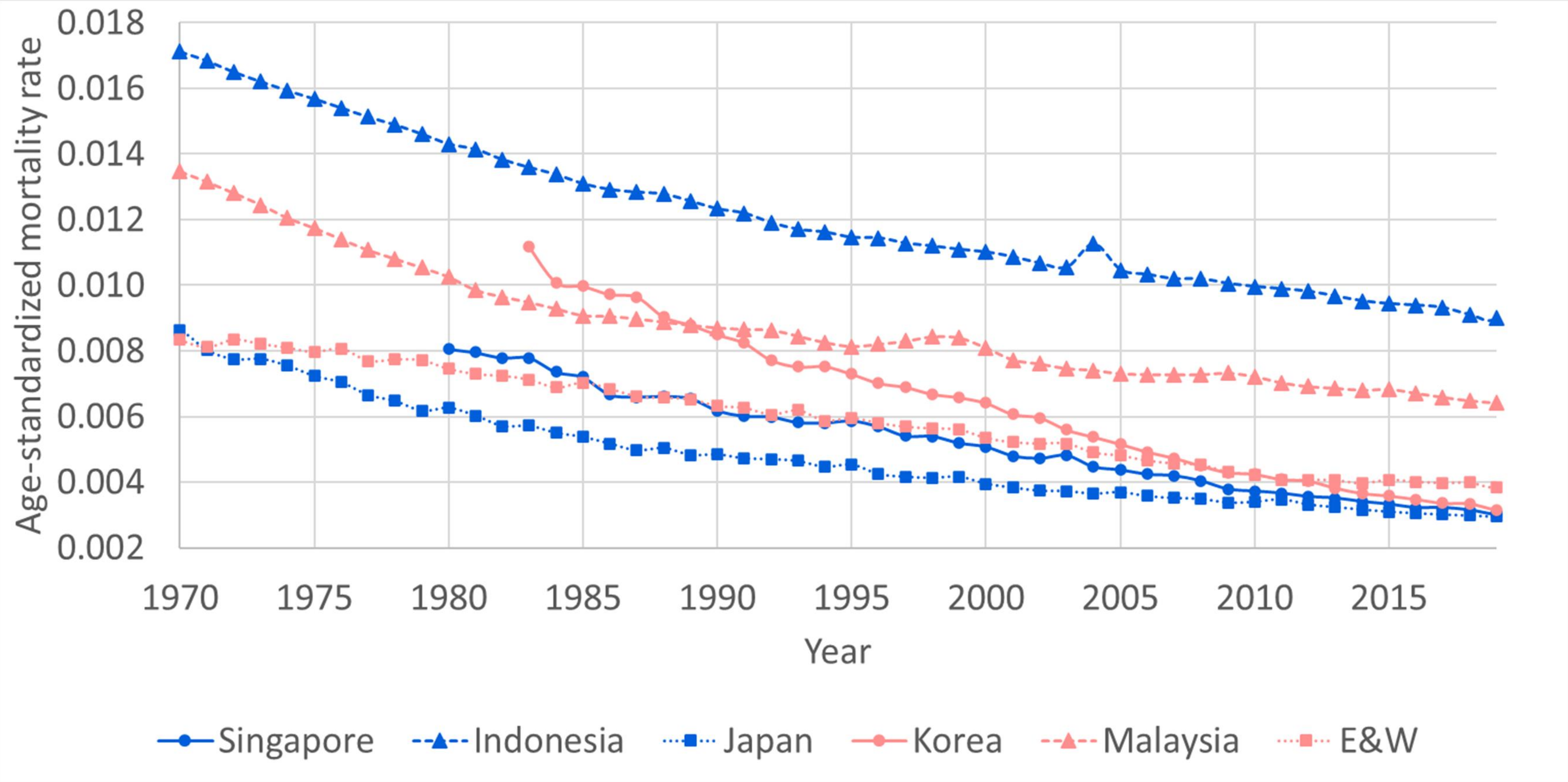
- Commonly referred to in published statistics and news
- Expected future lifetime for a *hypothetical* cohort that follows the age-specific mortality rates as of a certain time
- Static, point-in-time view of overall mortality level
- Assumes no mortality improvement in future

Cohort life expectancy

- Expected future lifetime for a *real* cohort that follows the natural evolution of mortality rate
- Indication of expected future lifetime of the cohort
- Assumption of future mortality rate required

Pre-pandemic mortality trend

Age-standardized mortality rate



- Long-term downward trend
- Distinctive levels of mortality rate by country
- Steep decrease in Singapore and Korea
- Deceleration of mortality improvement in Japan
- Implication for forecasting mortality improvement

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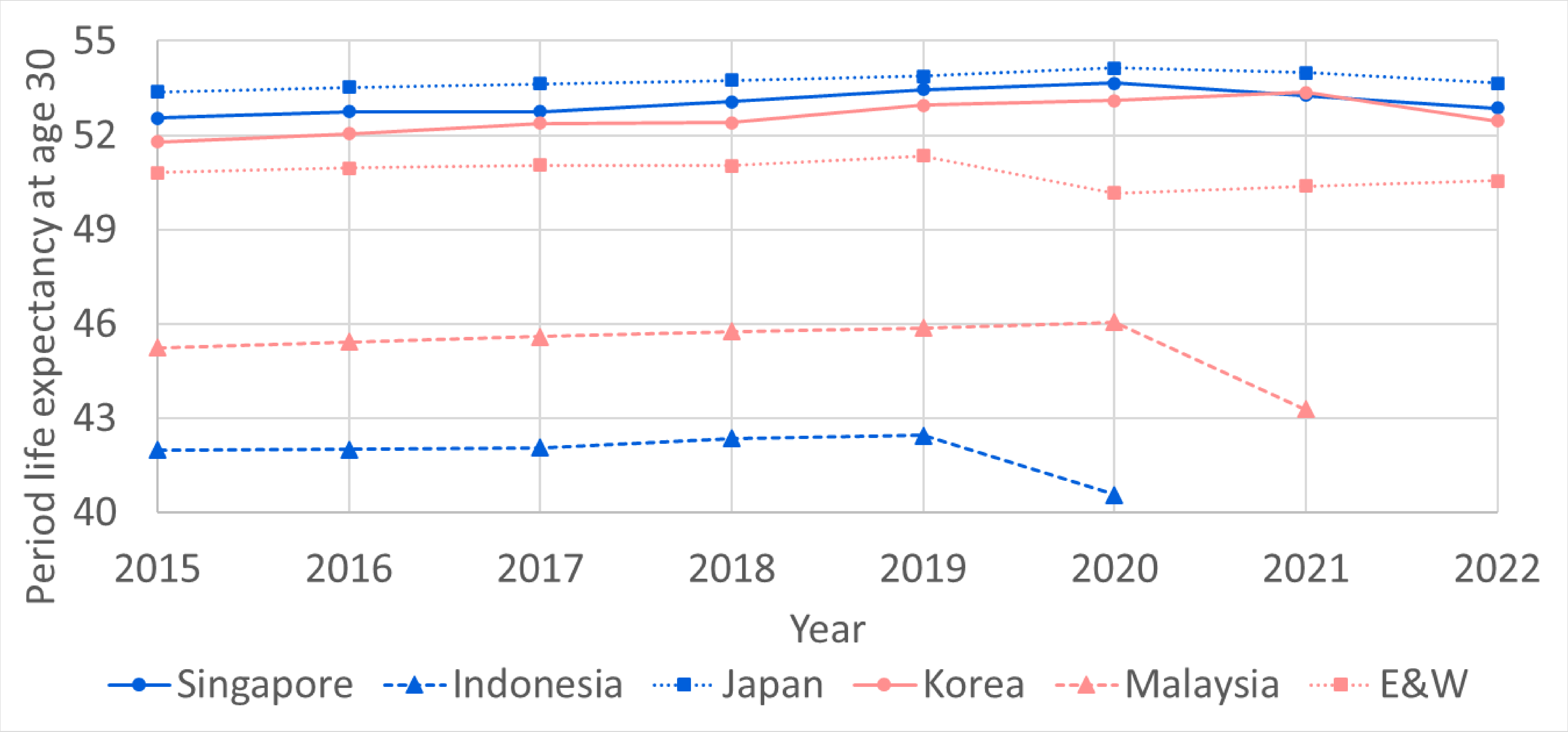
Mortality trend during pandemic

Factors impacting mortality during COVID

- Acute COVID-19 infection
- Delay/ avoidance of medical care, strain on the health care system
- Behavioural issues during the pandemic
- Reduction in other transmissible diseases
- Fewer road traffic and occupational accidents, reduced air pollution

Period life expectancy at age 30

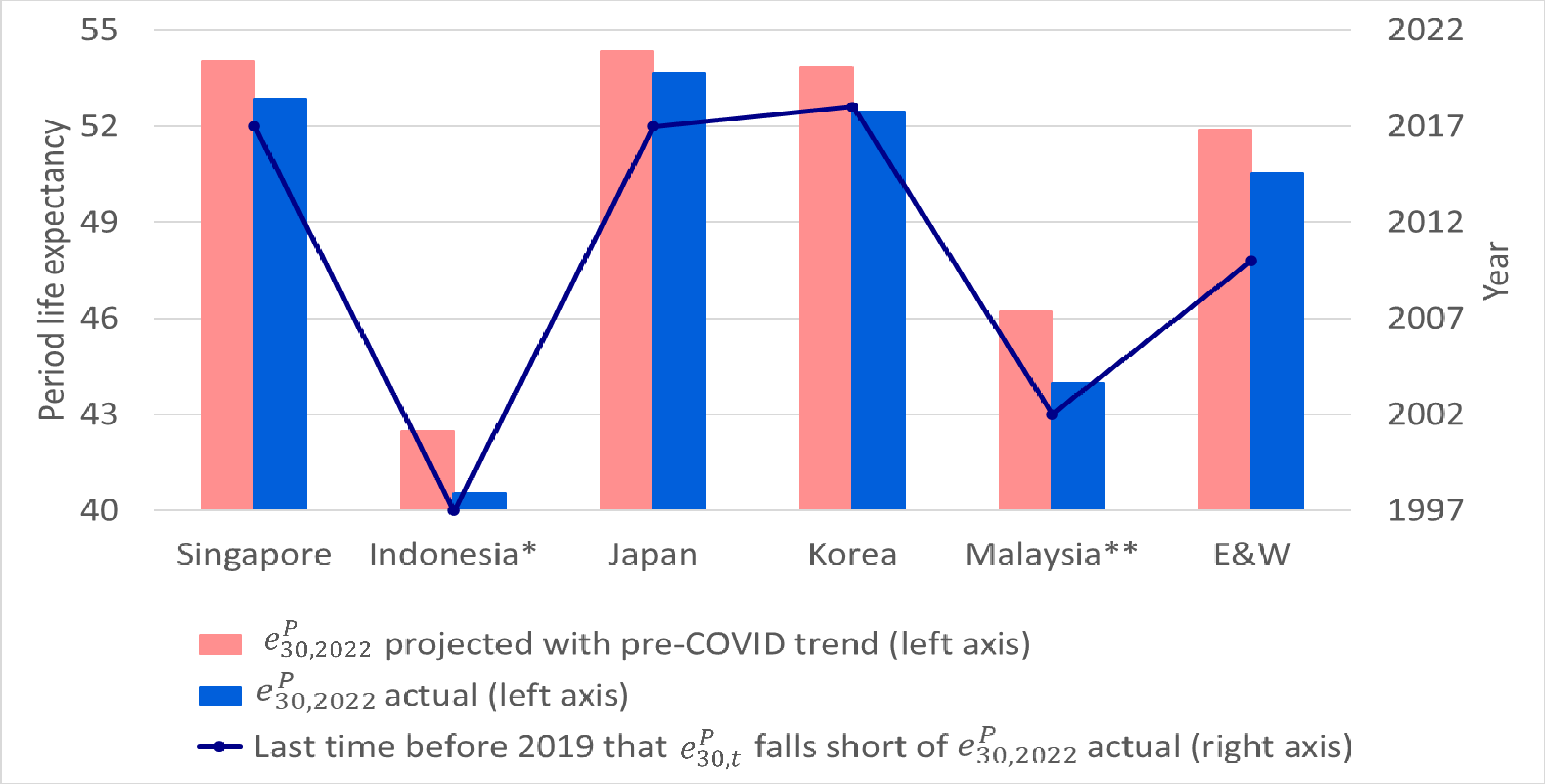
Impact from COVID-19 pandemic



- Singapore, Japan and Korea: small gain in mortality followed by moderate deterioration in mortality
- England & Wales: sizable decrease in life expectancy followed by small recoveries, but still not back to pre-pandemic level
- Indonesia and Malaysia: significant decrease in life expectancy although Malaysia had mortality gain in 2020

Period life expectancy at age 30

Actual vs. pre-pandemic expected



* Results as of 2020.

** 2022 actual based on simulation.

- Singapore, Japan and Korea: ~1 year difference actual vs. expected, worth ~5 years of mortality improvement
- England & Wales: ~1 year difference actual vs. expected but worth ~12 years of mortality improvement due to slow rate of improvement in recent years
- Indonesia and Malaysia: ~2 year difference actual vs. expected but worth about two decades of mortality improvement due to slow rate of improvement

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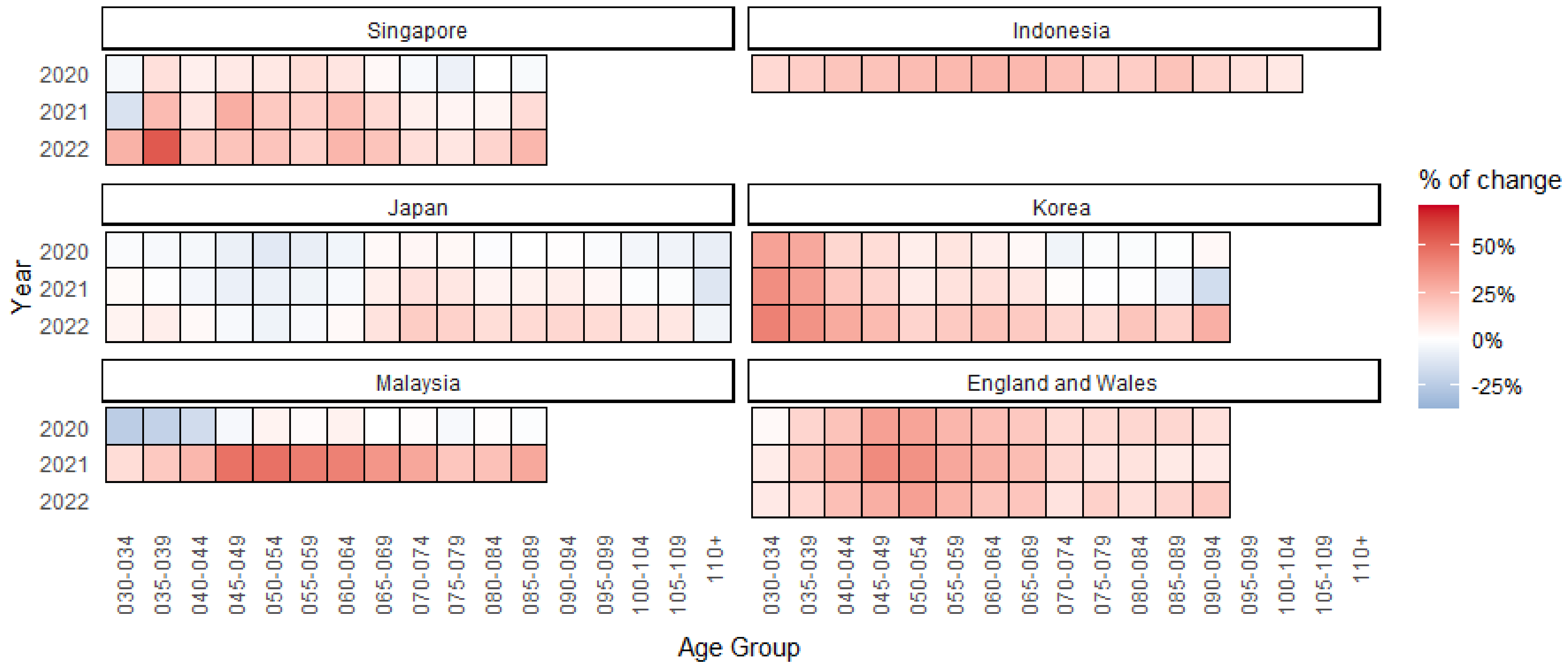
Excess mortality in pandemic

Age-specific excess mortality in pandemic

Excess mortality as % of expected mortality based on pre-pandemic trend



- Different impact by country and by year
- Some mortality gain in 2020/2021 in Singapore, Japan, Korea and Malaysia
- Younger ages had worse %-wise excess mortality than older ages in many countries
- Japan experienced the least impact overall

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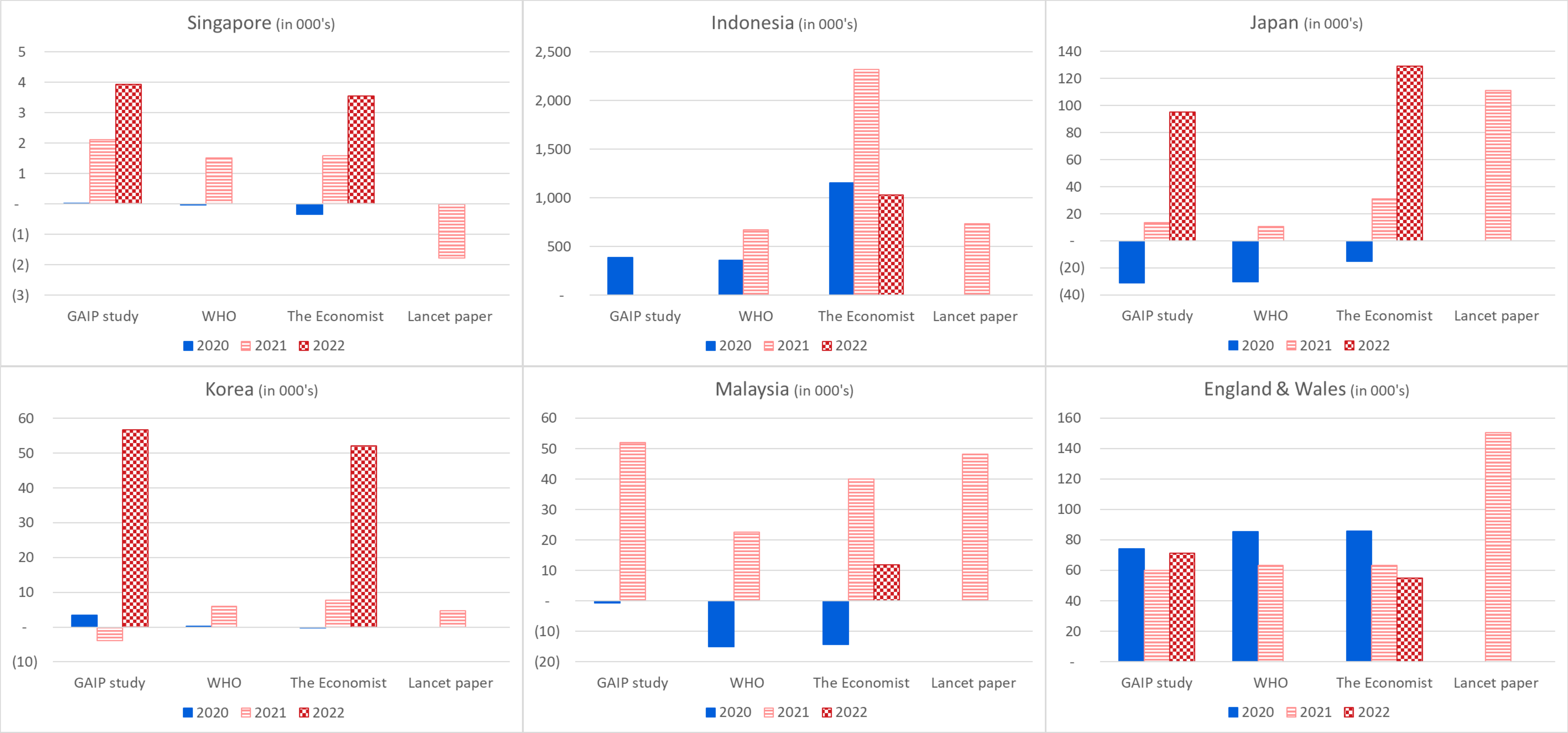
Various studies on estimated excess deaths

Number of excess deaths in 000's



- Excess death estimates highly dependent on measurement of expected deaths
- Many models estimate both actual and expected
- Lancet paper groups 2020 and 2021 result together
- Results from GAIP study are reasonably close to WHO's estimate
- The Economist estimates very significant excess deaths in Indonesia in 2021 and 2022

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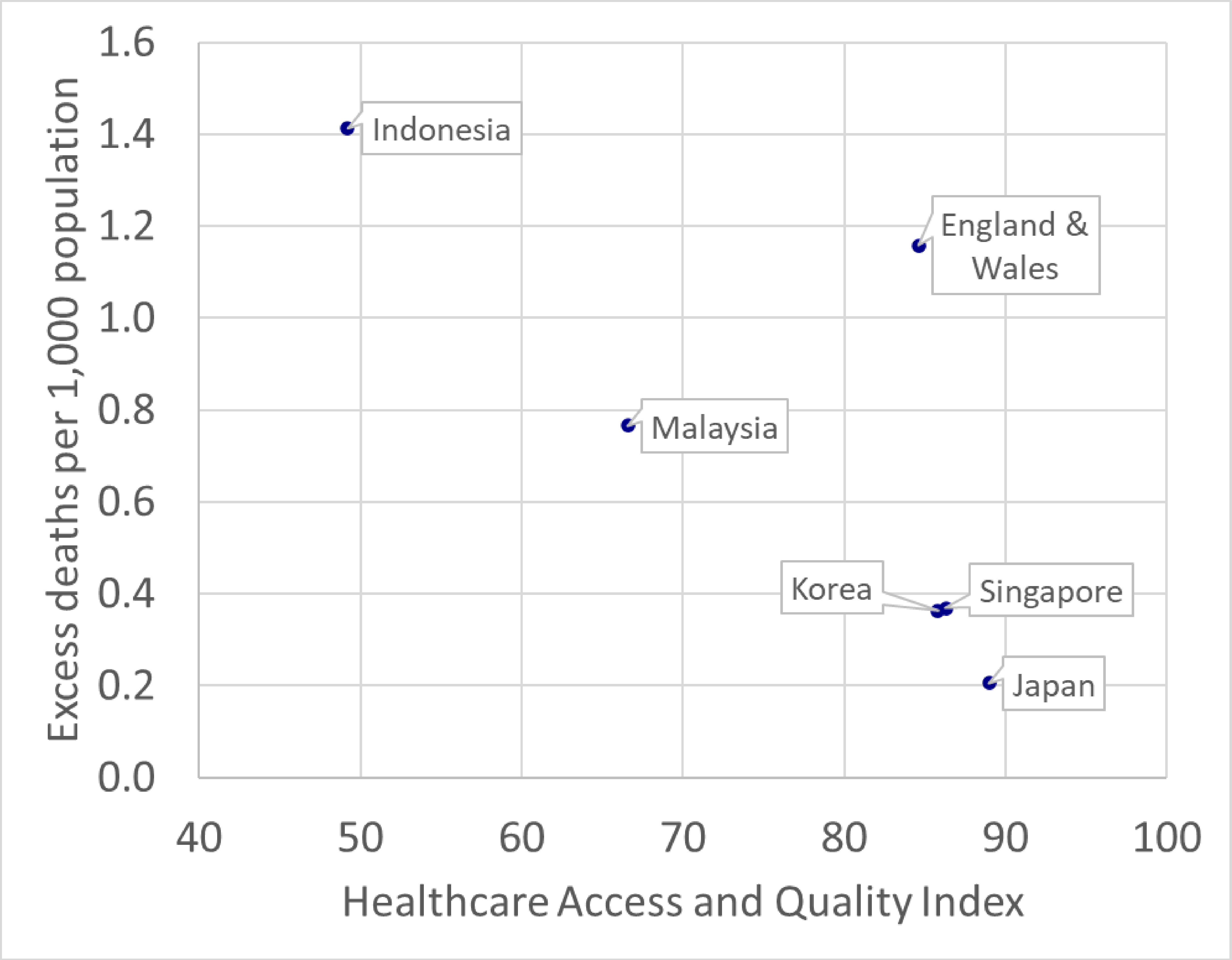
Excess deaths vs. healthcare access and quality

Average annual excess deaths per 1,000 population vs. Healthcare Access and Quality (HAQ) index



- Indication of negative correlation between excess deaths and HAQ index
- England & Wales seems to be an outlier
- Not adjusted for different age mix
- Only a preliminary exploration, study at bigger scale needed to draw any conclusion

Long-term mortality impact

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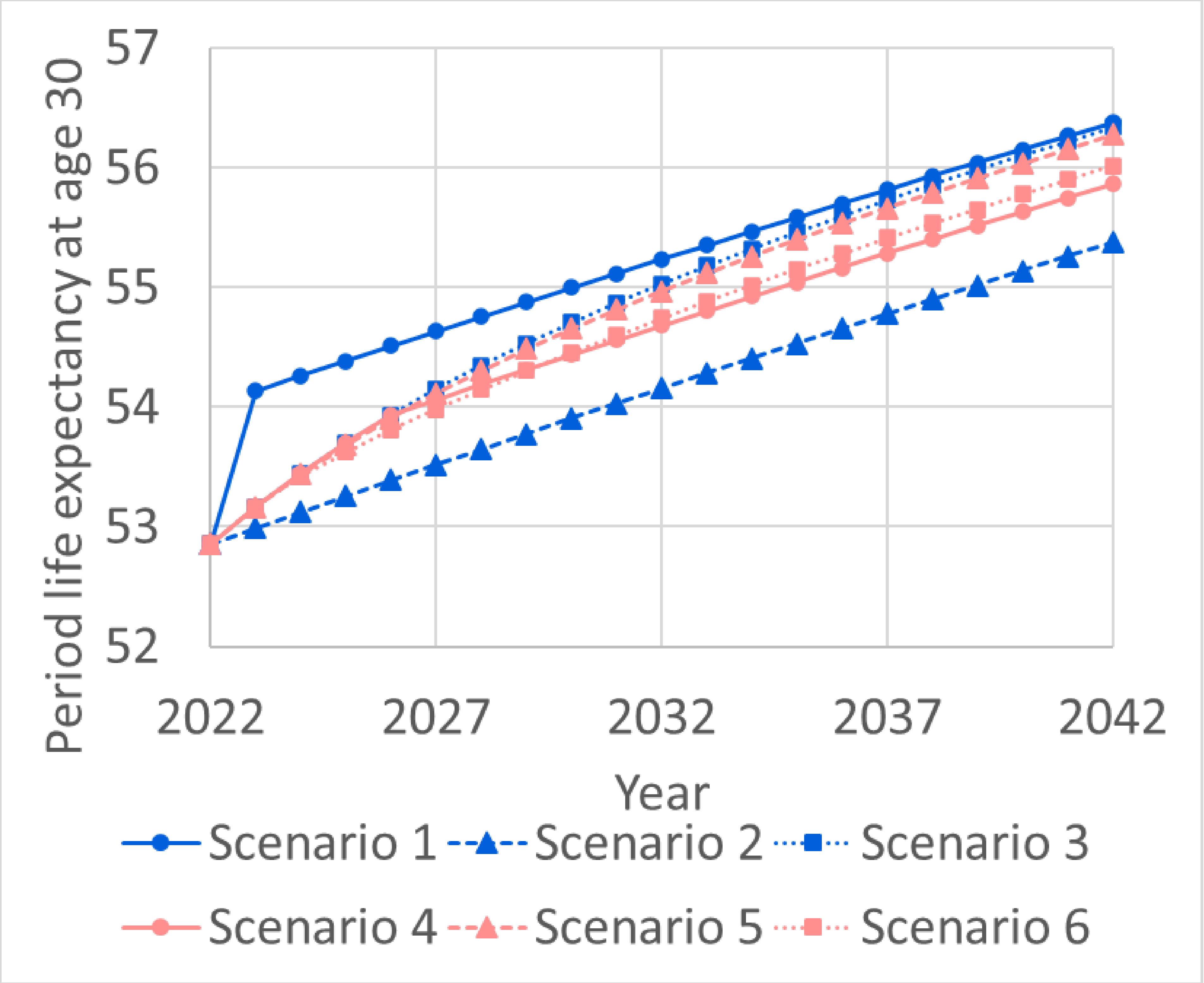
Simulation to forecast long-term mortality impact

Monte Carlo simulation of future mortality rates under 6 scenarios

- Scenario 1: COVID-19 mortality shock **disappears completely and immediately**, no new pandemic occurs
- Scenario 2: COVID-19 mortality shock **continues indefinitely**, no new pandemic occurs
- Scenario 3: COVID-19 mortality shock **subsides gradually and indefinitely**, no new pandemic occurs
- Scenario 4: COVID-19 mortality shock **subsides gradually but only for 4 years**, no new pandemic occurs
- Scenario 5: **Scenario 3**, plus a **new pandemic** occurs with a **probability of 0.01** each year
- Scenario 6: **Scenario 3**, plus a **new pandemic** occurs with a **probability of 0.05** each year

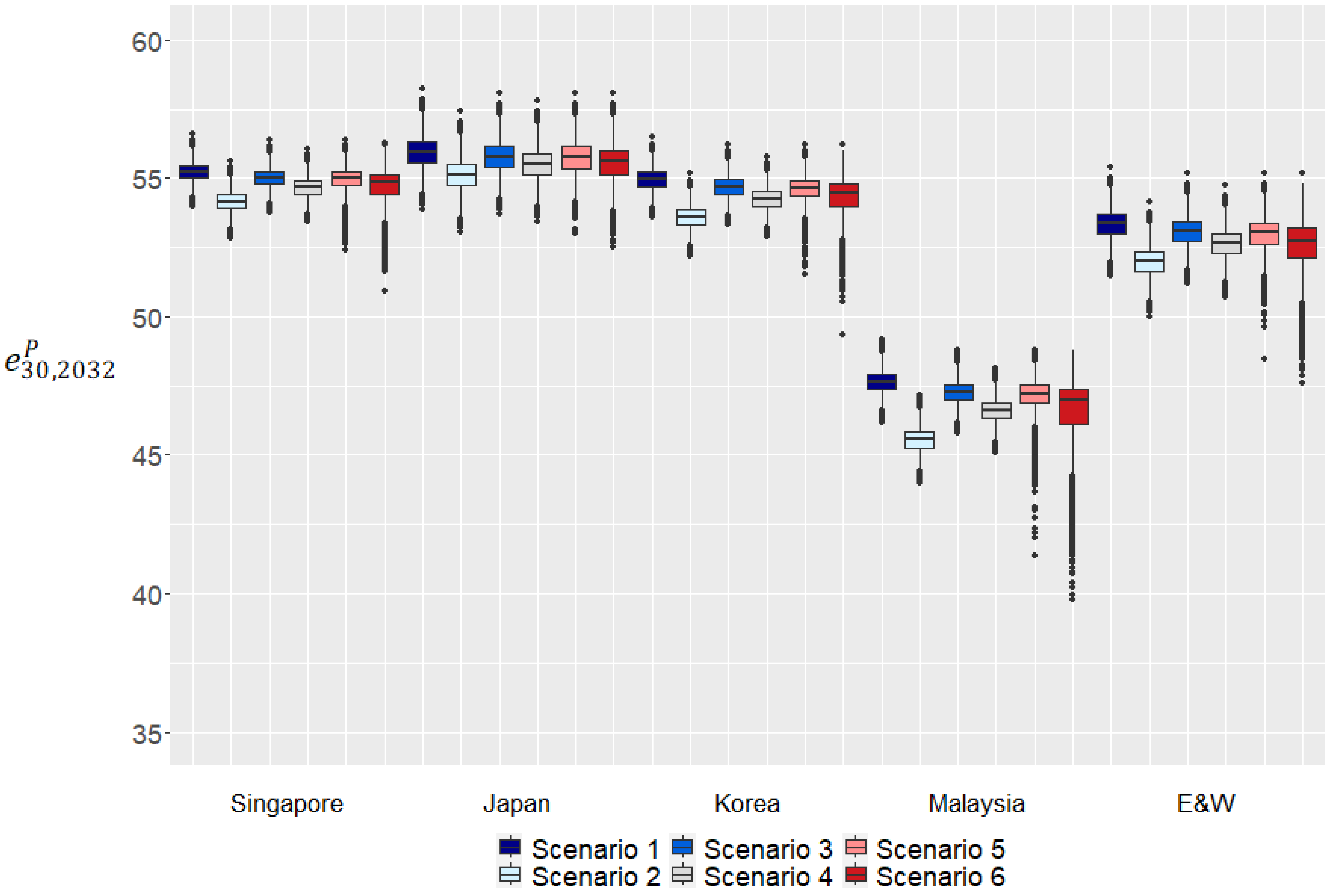


Simulation to forecast long-term mortality impact

Monte Carlo simulation of future mortality rates under 6 scenarios

- Under each scenario, generate 10,000 Monte Carlo simulation sample paths of death rates
- Calculate statistics such as life expectancy for each sample path

Period life expectancy at age 30 in year 2032



- Indication of overall mortality level in 2032
- Scenarios assuming arrival of new pandemic (scenario 5 and 6) show significant left-tail risk (shorter life expectancy)
- Scenario 3-6 are plausible given historical long-term volatility: first and third quartile in Scenario 3-6 are within the data range of Scenario 1.
- Variation between scenarios dictated by magnitude of COVID mortality shock in each country

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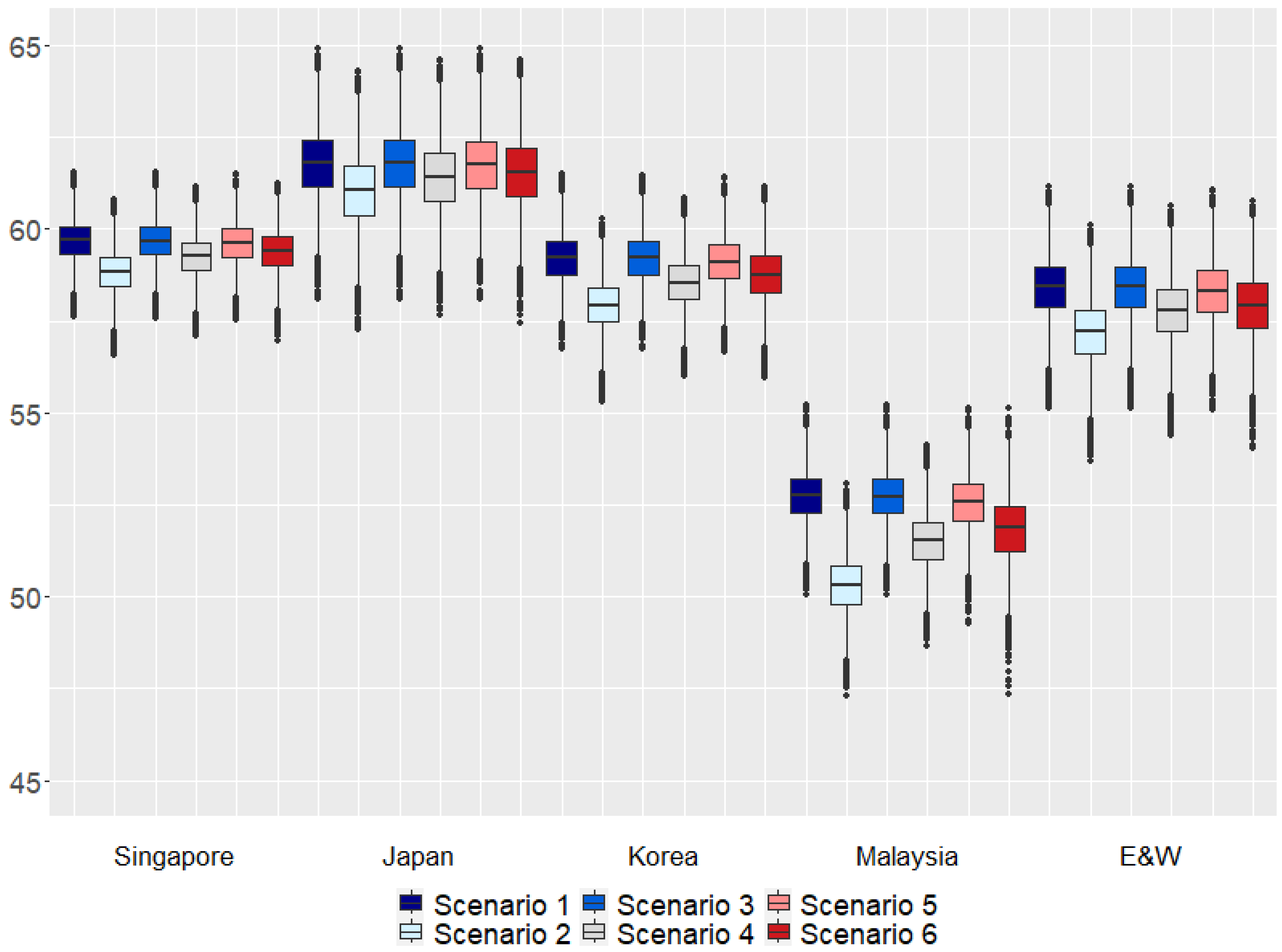
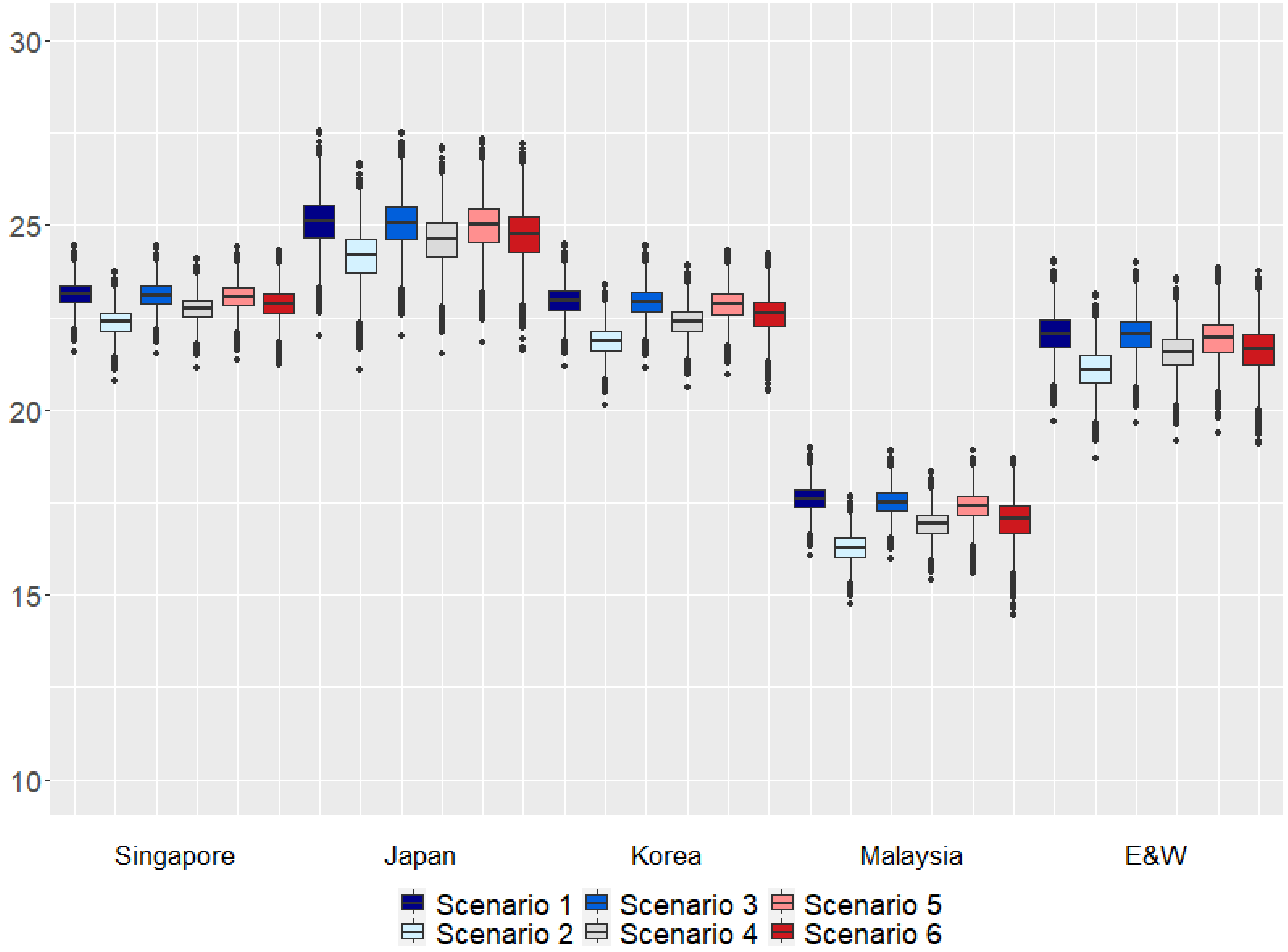
Cohort life expectancy at age 30 in year 2032



- Indication of future lifetime of age 30 in 2032
- Less variation among scenarios than period life expectancy due to pandemic mortality shock gradually absorbed by future mortality improvement
- Larger variance than period life expectancy due to randomness in future mortality improvement
- Significant longevity risk in Singapore, Japan, Korea and E&W

Cohort life expectancy at age 65 in year 2032



- Smaller variance than cohort life expectancy at age 30 due to much shorter projection horizon

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Implications, recommendations and limitations

Implications and recommendations

Experience monitoring and data collection

- Great variation in COVID-related mortality shock and long-term mortality trend among different countries
- Mortality trend can change rather quickly in Asian countries so close monitoring is crucial
- Embrace new technology and collaboration

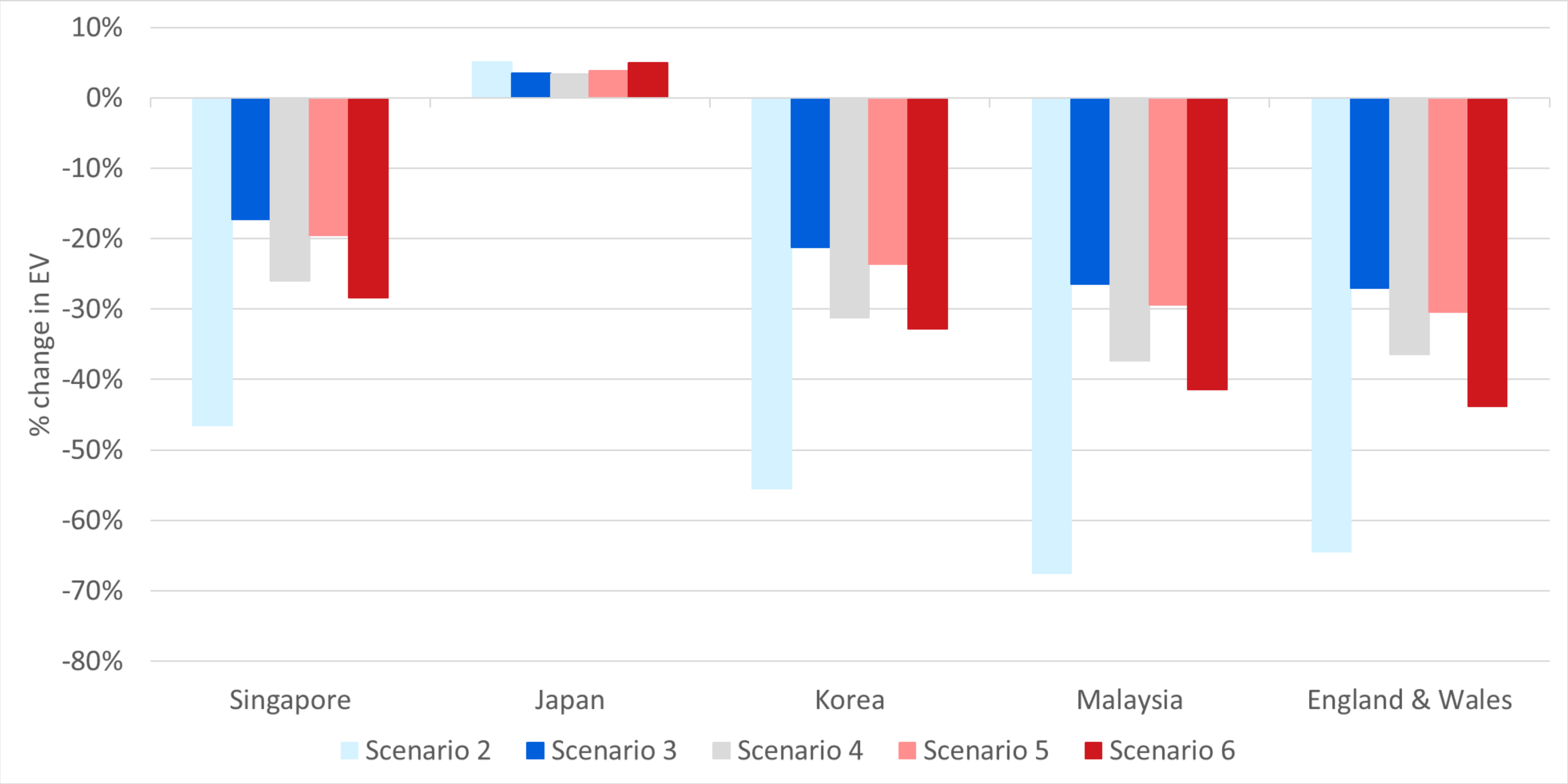
Mortality modelling

- The stochastic mortality model presented in this study can be used to quantify and estimate COVID-related impact
- Extension can be made to quantify other short-term mortality shocks

Implications and recommendations

Risk Management

- Mortality impact during COVID may have significant profitability impact
- Example: % change in EV at YE 2022 of Term 20 life insurance contract of age 45



Implications and recommendations

Risk Management

- Need for studying profitability impact under different scenarios
- Incorporate insights from COVID-19 impact into scenario analysis and stress testing
- Maintain a diverse portfolio
- Improve access and quality to healthcare
- Longevity risk remains critical

Implications and recommendations

Protection gap

- Mortality protection gap: material impact on mortality of younger age group in Indonesia and Malaysia
- Longevity protection gap: long life expectancy in developed economies in Asia
- Health protection gap: better health protection likely be correlated with better mortality outcome during pandemic

Morbidity impact

- Impact from the pandemic and long-COVID
- Future study with industry collaboration necessary

Limitations

- Limitation of our stochastic mortality model: deterministic mortality shock and identical pattern in future pandemics
- Limitation of modelling for quantifying excess deaths: not suitable for estimating excess deaths in small time interval
- Study based on population rather than insured lives data
- Study based on data up to 2022, longer-term monitoring necessary
- Morbidity impact not considered

Stochastic mortality models

Lee-Carter model

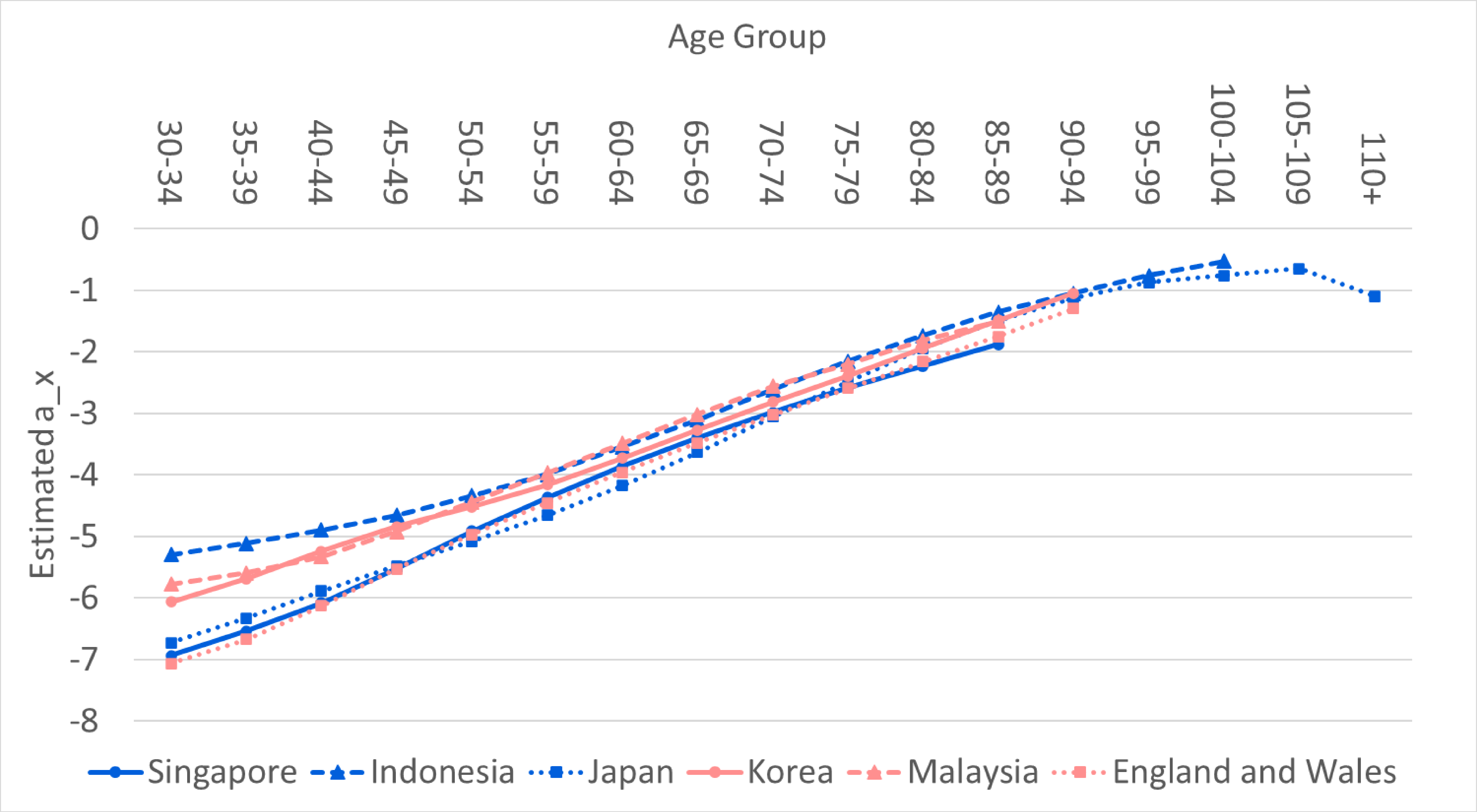
- $m_{x,t}$ denotes central death rate at age x in year t
- The model: $\log m_{x,t} = a_x + b_x k_t + \xi_{x,t}$
- k_t follows a random walk with drift such that $k_t = k_{t-1} + \mu + \epsilon_t$, $\epsilon_t \overset{i.i.d.}{\sim} N(0, \sigma^2)$
- a_x: long-term average log central death rate of age x over data period
- k_t: captures overall level of mortality improvement over time, a.k.a. the mortality index
- b_x: reflects age x's sensitivity to changes in k_t
- Constraints to ensure uniqueness of parameter value: $\sum_x b_x = 1$, $k_t = 0$

Lee-Carter model

- Concise form with intuitive interpretation
- Captures overall long-term trend, age-specific characteristic and random fluctuation
- Does not capture any shock
- Does not capture any cohort effect
- Two-stage parameter estimation process

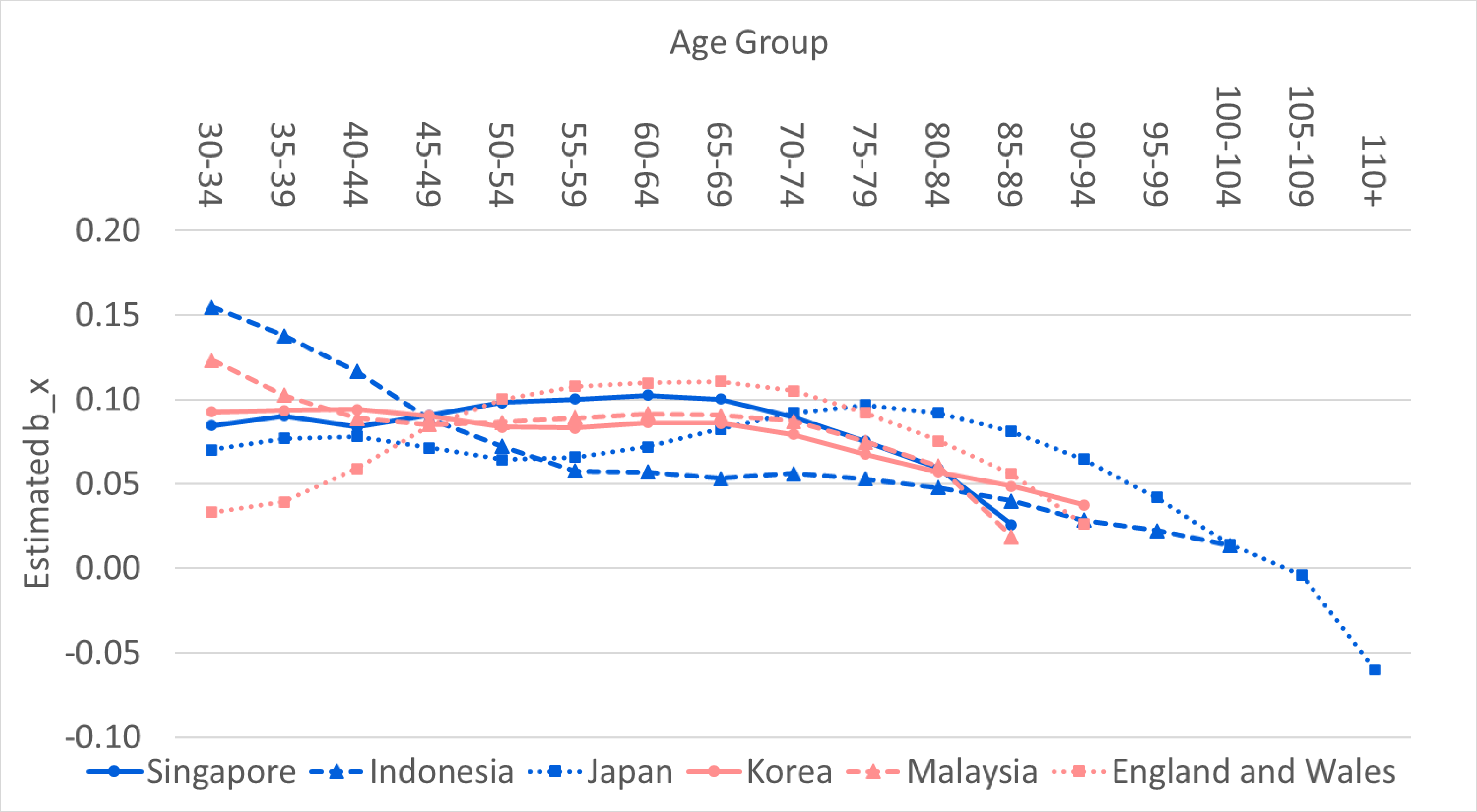
Lee-Carter model

Estimated a_x with pre-COVID data



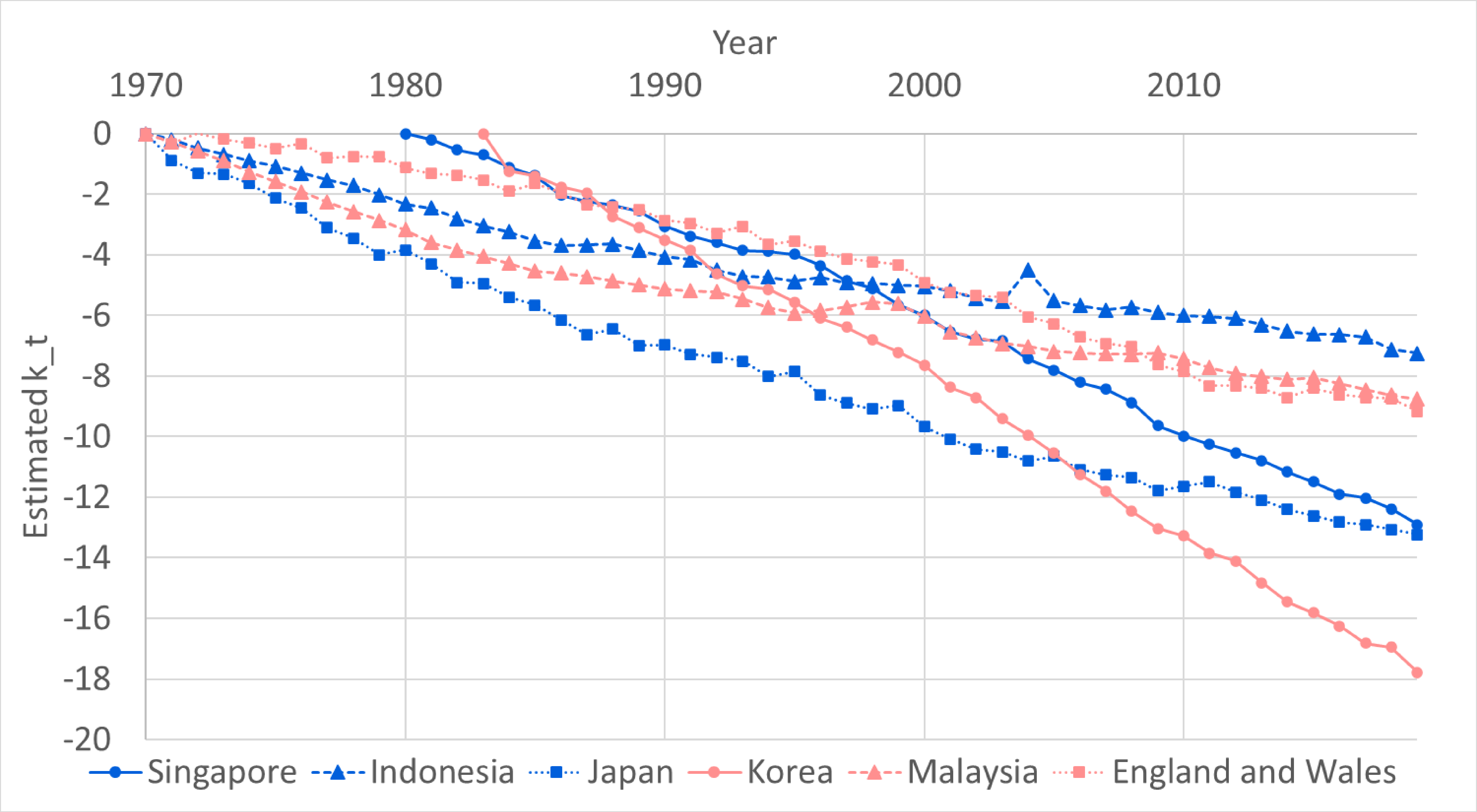
Lee-Carter model

Estimated b_x with pre-COVID data



Lee-Carter model

Estimated k_t with pre-COVID data



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Two-parameter-level model

- Zhou, Rui, and Johnny Siu-Hang Li. "A multi-parameter-level model for simulating future mortality scenarios with COVID-alike effects." *Annals of Actuarial Science* 16.3 (2022): 453-477.

- The model: $\log m_{x,t} = a_x + b_x k_t + c_{x,t} \pi_t \mathbf{1}_{t \in \mathcal{T}}$

- $\mathbf{1}_{t \in \mathcal{T}}$ is an indicator function with value of 1 if year t is a pandemic year

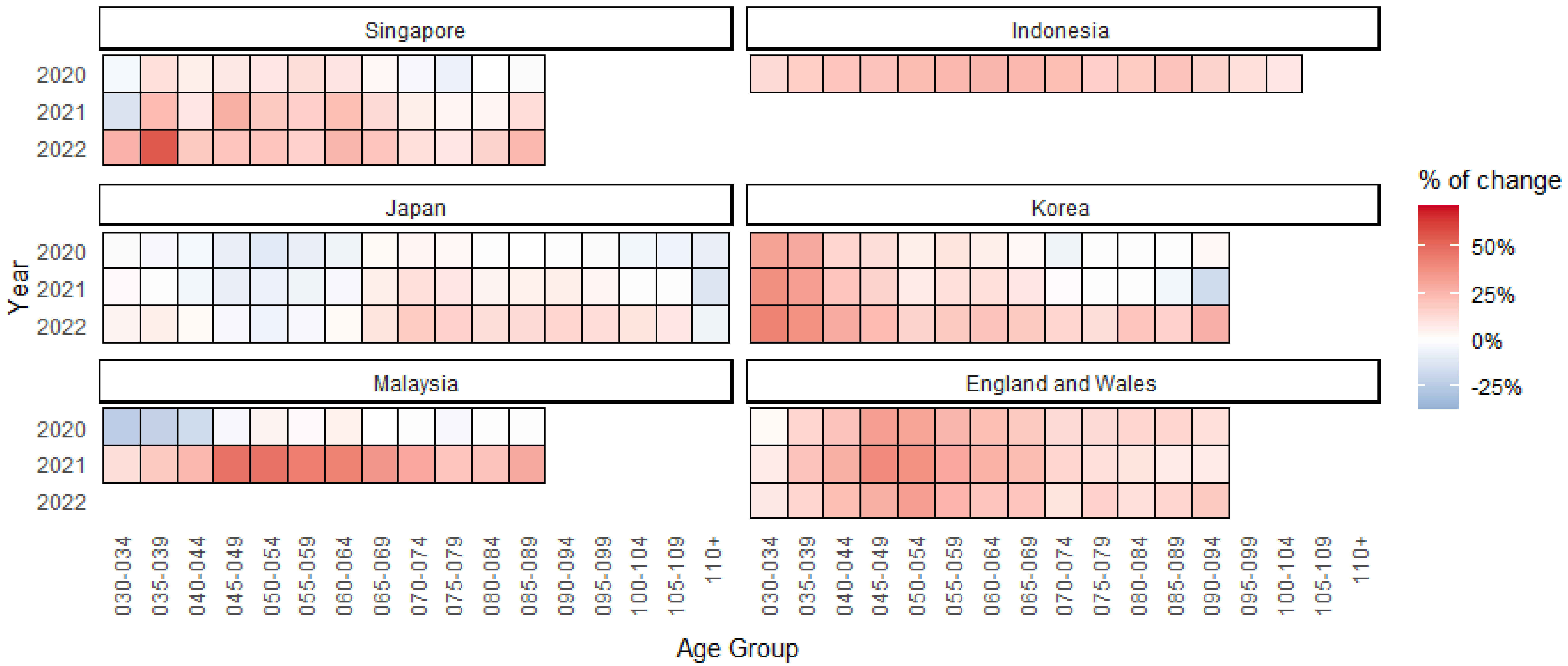
- π_t captures time specific overall mortality shock in pandemic

- $c_{x,t}$ captures age specific mortality impact, which also varies by time, relative to π_t

- Constraints to ensure uniqueness of parameter value: $\sum_x b_x = 1, \quad k_t = 0, \quad \sum_x c_{x,t} = 1.$

Age-specific excess mortality in pandemic

Excess mortality as % of expected mortality based on pre-pandemic trend



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- Some mortality gain in 2020/2021 in Singapore, Japan, Korea and Malaysia
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Parameter estimation

- Maximize penalized quasi-likelihood (PQL), $g(\theta)$, for estimating $\theta \in \{a_x, b_x, k_t, c_{x,t}, \pi_t, \mu\}$
- Maximize approximate profile quasi-likelihood function, $h(\theta)$, for estimating $\theta \in \{\sigma\}$
- Iterative process using Newton's method
- PQL penalizes deviation from a multivariate normal distribution of $\boldsymbol{k}$
- Capable of disentangling COVID mortality shock and fluctuation in long-term mortality improvement

Parameter estimation

Algorithm for parameter estimation

initialize: Initialize parameter values as

1. Set $a_{x_{prev}}$ = estimated a_x using the Lee-Carter model;
2. Set $b_{x_{prev}} = c_{x,t_{prev}}$ = estimated b_x using the Lee-Carter model;
3. Set $k_{t_{prev}} = \pi_{t_{prev}}$ =estimated k_t using the Lee-Carter model;
4. Set μ_{prev} = estimated μ using the Lee-Carter model;
5. Set σ_{prev} = estimated σ using the Lee-Carter model;
6. $\delta = \eta = 1$;
7. Update $g_{prev}(\theta) \leftarrow g(\theta)$;
8. Update $h_{prev}(\theta) \leftarrow h(\theta)$;

while $\delta > 0.0001$ **do**

  while $\eta > 0.0001$ **do**

    for $\theta \in \{a_x, b_x, k_t, c_{x,t}, \pi_t, \mu\}$ **do**

      Update $\theta_{curr} \leftarrow \theta_{prev} - \frac{\frac{\partial}{\partial\theta}g(\theta_{prev})}{\frac{\partial^2}{\partial\theta^2}g(\theta_{prev})}$

    end

    Update $\eta = g(\theta_{curr}) - g_{prev}(\theta)$

    Update $\theta_{prev} \leftarrow \theta_{curr}$

    Update $g_{prev}(\theta) \leftarrow g(\theta_{curr})$

  end

  } maximize $g(\theta)$

  Update $\sigma_{curr} \leftarrow \sigma_{prev} - \frac{\frac{\partial}{\partial\sigma}h(\sigma_{prev})}{\frac{\partial^2}{\partial\sigma^2}h(\sigma_{prev})}$

  Update $\delta = h(\sigma_{curr}) - h_{prev}(\sigma)$

  Update $\sigma_{prev} \leftarrow \sigma_{curr}$

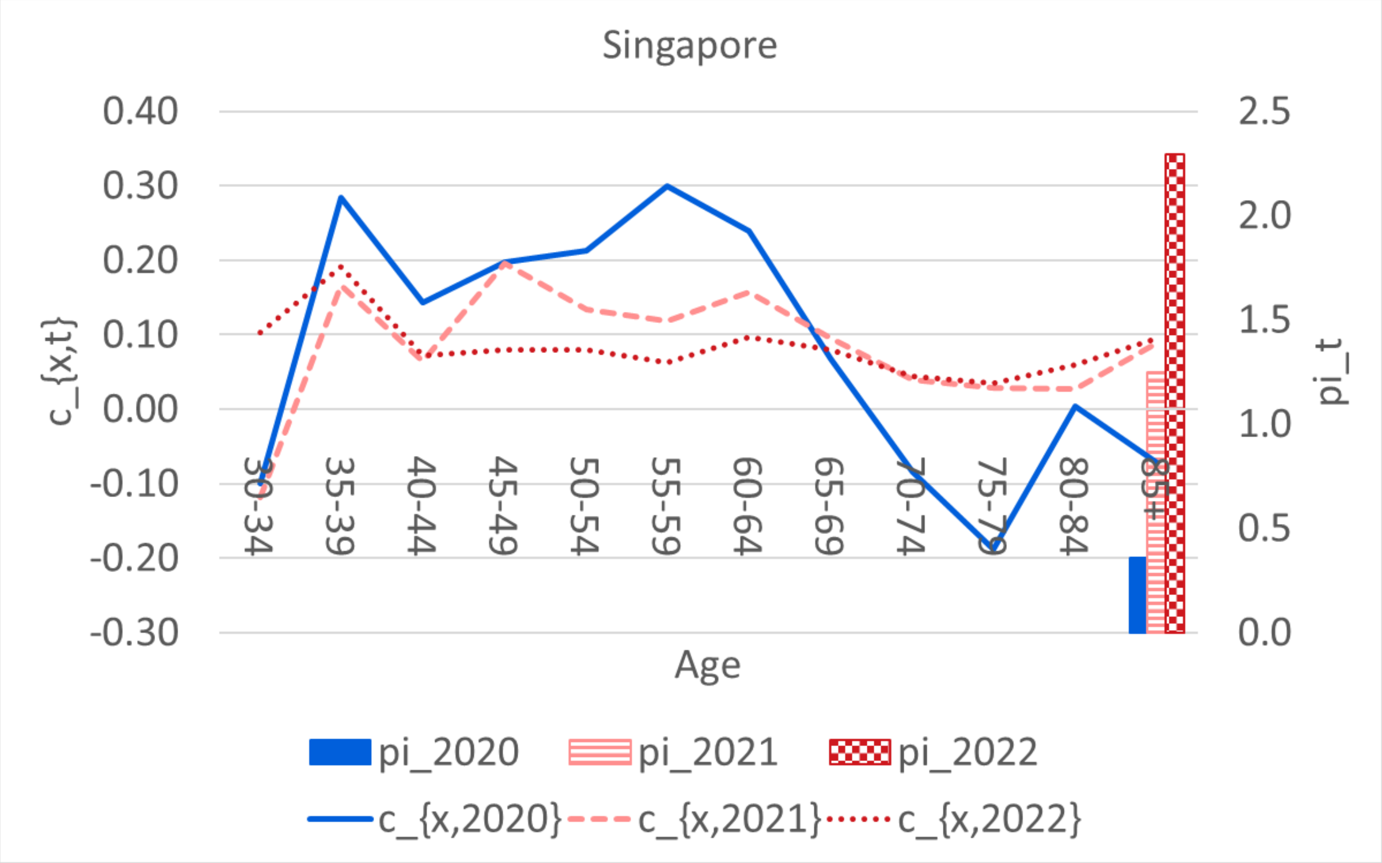
  Update $h_{prev}(\sigma) \leftarrow h(\sigma_{curr})$

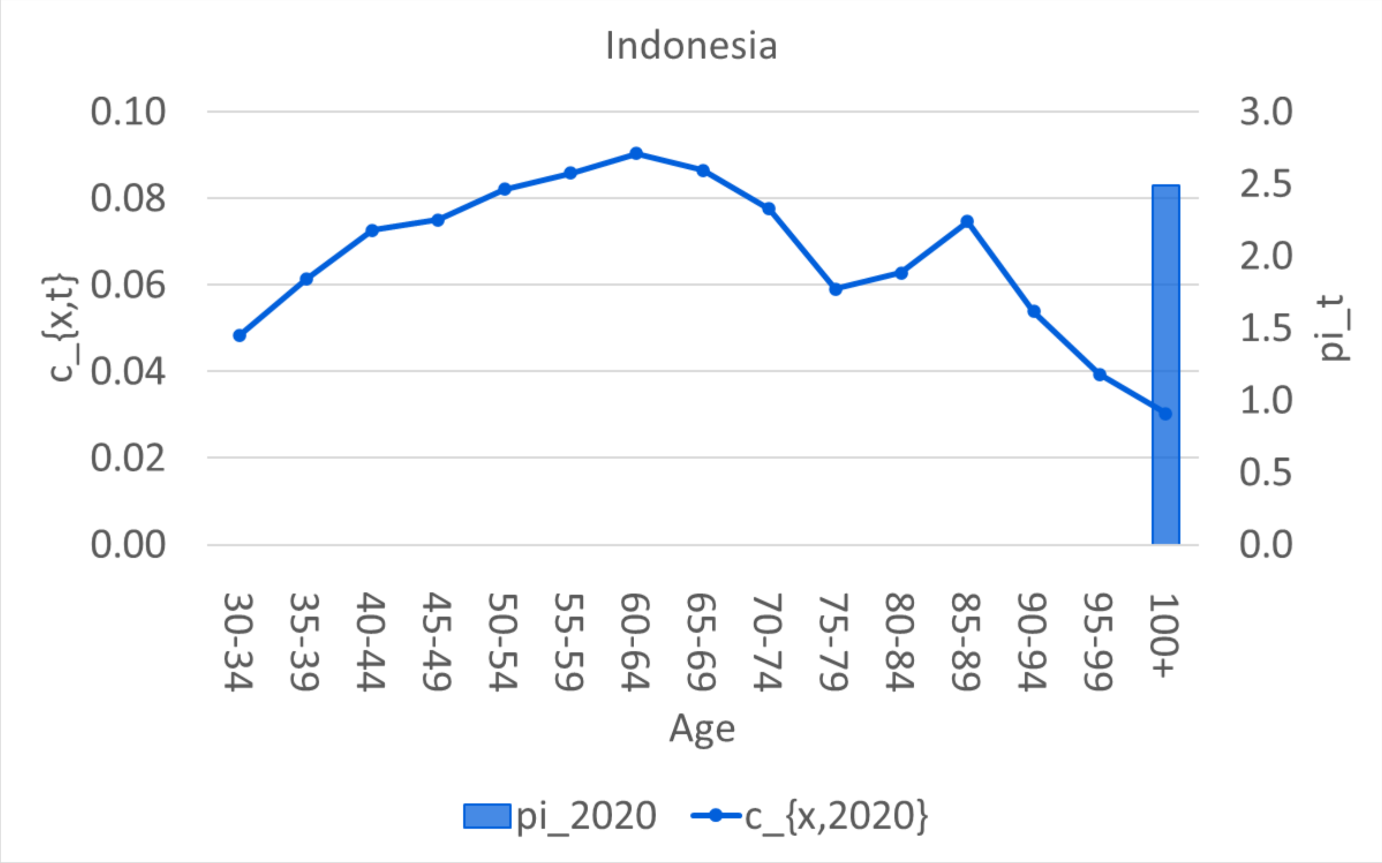
  } maximize $h(\theta)$

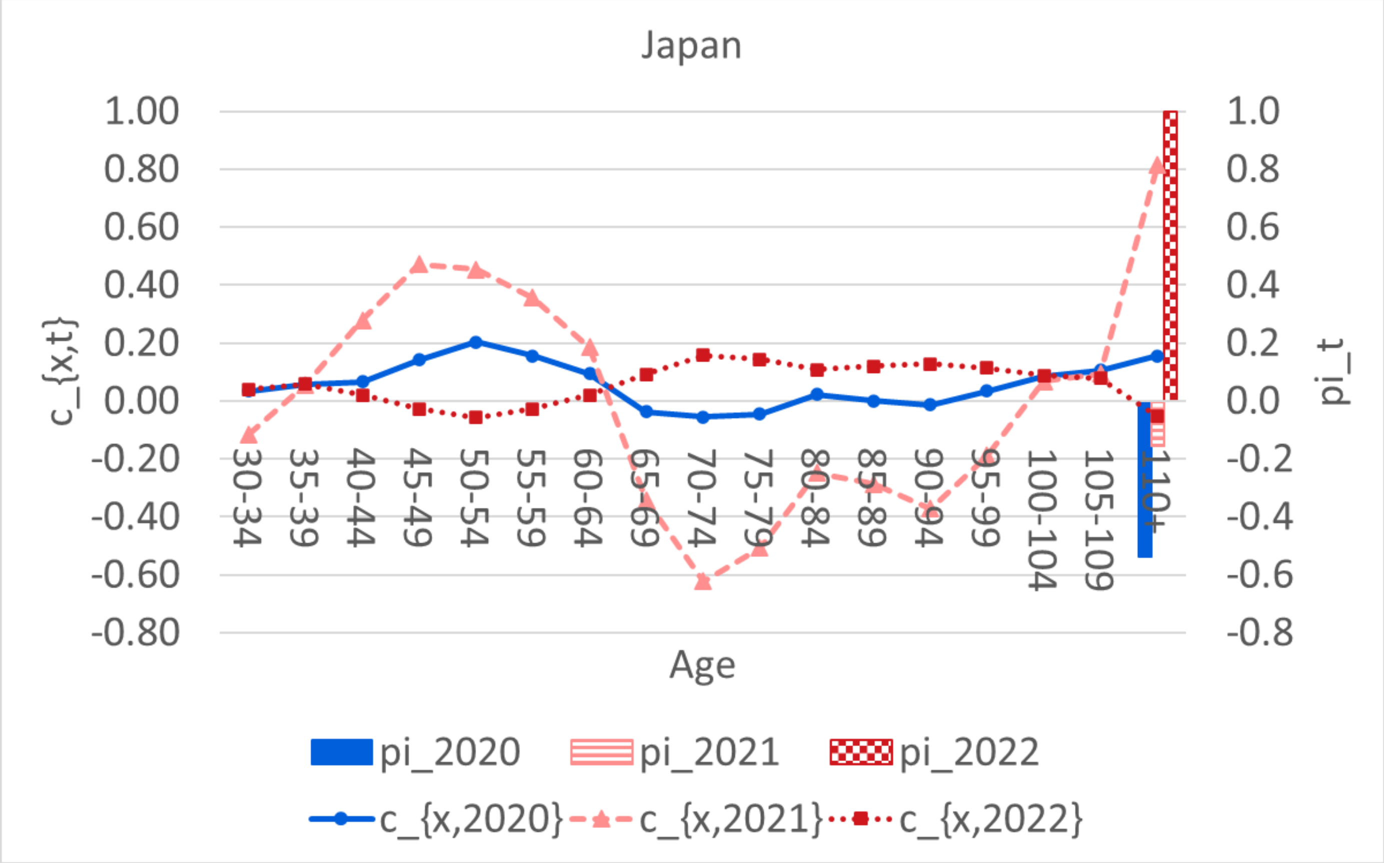
end

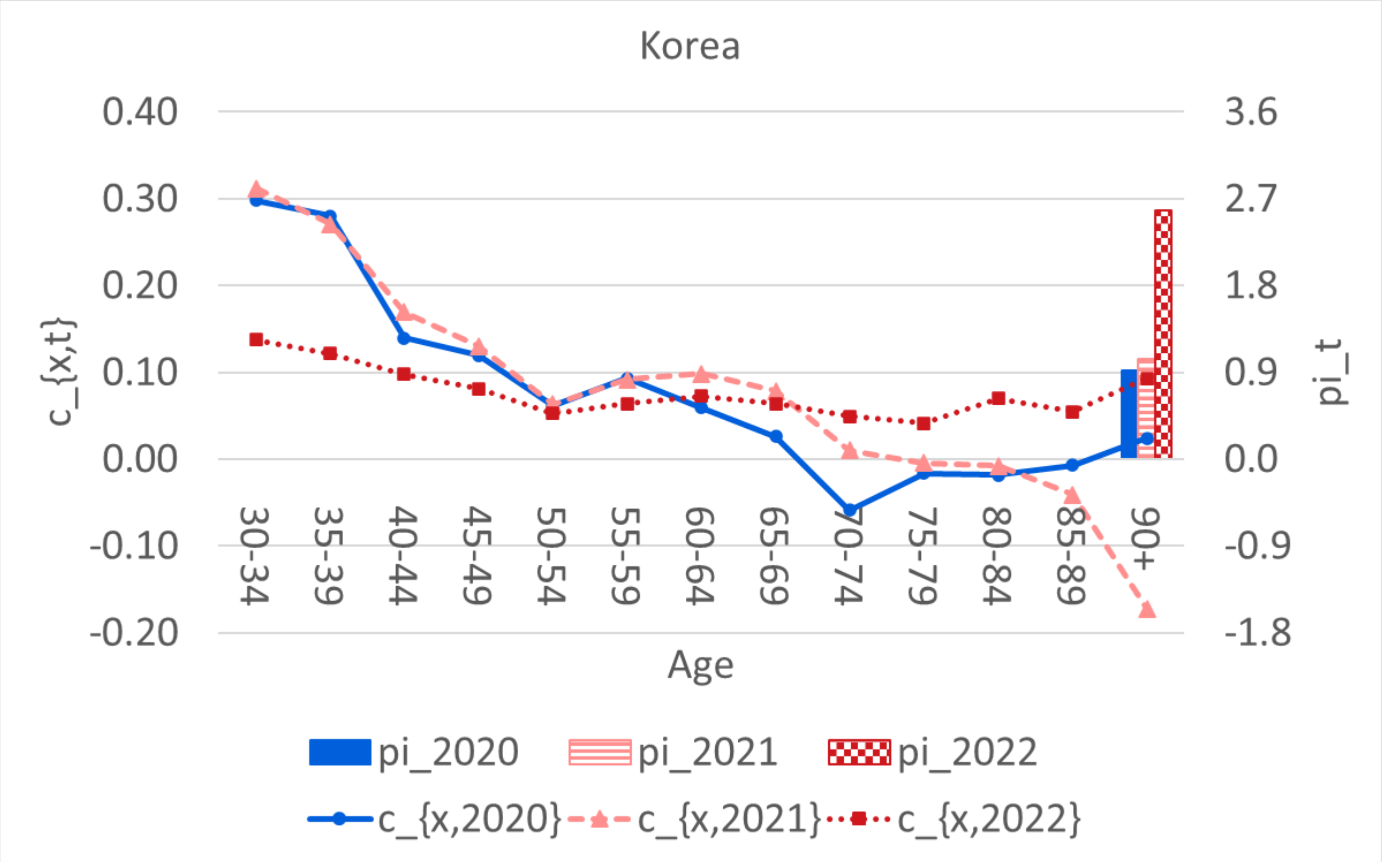
Parameter estimation

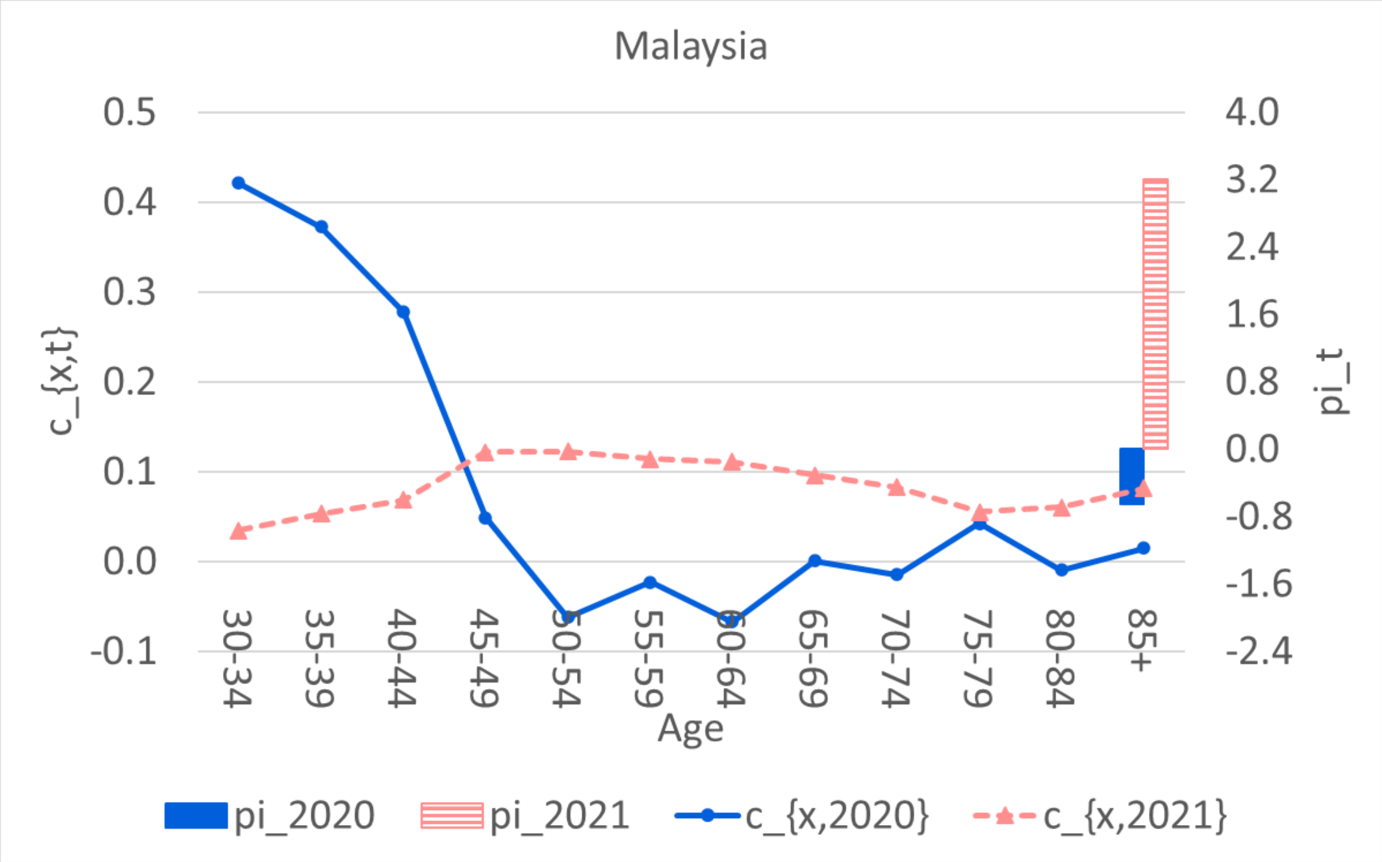
Estimated parameters

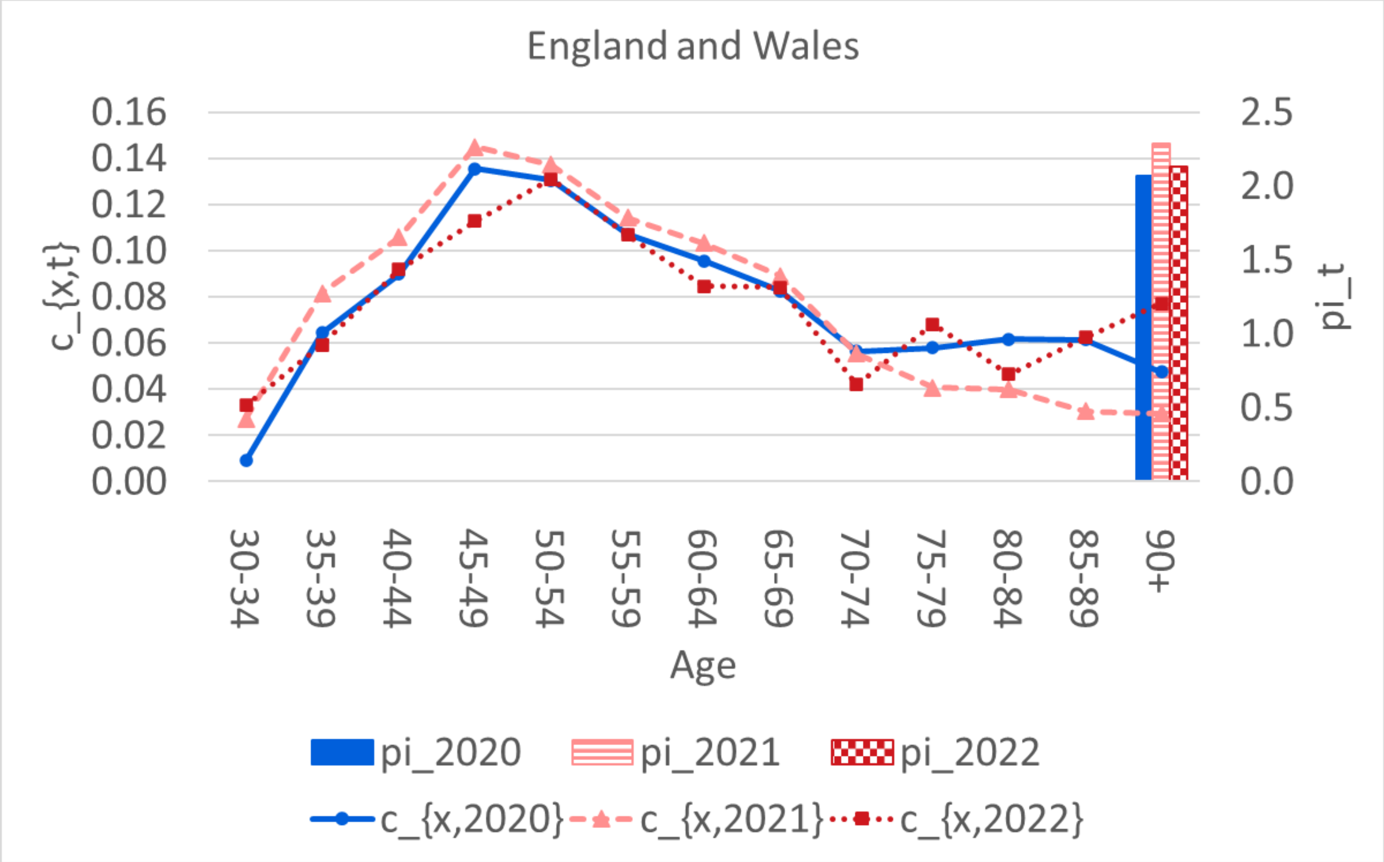












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Simulation using two-parameter-level model

- Simulation model

$$\log m_{x,t} = a_x + b_x k_t + \sum_i \Big(\underbrace{c_{x,t}^{(i)} \pi_t^{(i)} \mathbf{1}_{T_1^{(i)} \le t \le T_k^{(i)}}}_{\text{pandemic phase}} + \underbrace{c_{x,T_k}^{(i)} \pi_{T_k}^{(i)} \gamma^{g\left(t,T_k^{(i)}\right)} \mathbf{1}_{t > T_k^{(i)}}}_{\text{endemic phase}} \Big)$$

where $\mathbf{1}_t = \begin{cases} 1 \text{ with probability } p \\ 0 \quad\quad\quad \text{otherwise} \end{cases}$ for any $t > T_k^{(1)}$

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Parameter setup	$i = 1,\quad p = 0,$ $\gamma = 0,$ $g\left(t, T_k^{(i)}\right) = t - T_k^{(i)}$	$i = 1,\quad p = 0,$ $\gamma = 1,$ $g\left(t, T_k^{(i)}\right) = t - T_k^{(i)}$	$i = 1,\quad p = 0,$ $0 < \gamma < 1,$ $g\left(t, T_k^{(i)}\right) = t - T_k^{(i)}$	$i = 1,\quad p = 0,$ $0 < \gamma < 1,$ $g\left(t, T_k^{(i)}\right) = min(t - T_k, 4)$	$i \ge 1,\quad p = 0.01,$ $0 < \gamma < 1,$ $g\left(t, T_k^{(i)}\right) = t - T_k^{(i)}$	$i \ge 1,\quad p = 0.05,$ $0 < \gamma < 1,$ $g\left(t, T_k^{(i)}\right) = t - T_k^{(i)}$

Simulation using two-parameter-level model

Algorithm for simulation under each scenario

input: Estimated values of a_x, b_x, k_{t_n}, c_{x,t_n}, π_{t_n}, μ, σ and p ;

N: number of simulation samples;

T: number of years to forecast in simulation;

initialize: Set $\mu = [\mu, 2\mu\ \dots, T\mu]$;

Set the (i,j)-th entry of the $T \times T$ variance-covariance matrix V to be $V_{ij} = (\min(i,j) - 1)\sigma^2$;

for $i = 1$ to N **do**

Randomly sample $\boldsymbol{z}_i$ from $MVN(\mu, V)$

Set $\boldsymbol{k}_i = [k_{t_n+1}, k_{t_n+2}, \dots, k_{t_n+T}]' = k_{t_n} + \boldsymbol{z}_i$;

Randomly sample $\mathbf{1}_{\boldsymbol{i},t}$ for $t = t_n + 1, \dots, t_n + T$ from i.i.d. Bernoulli(p);

Compute $\log m_{x,t}$ for $t = t_n + 1, \dots, t_n + T$;

Compute $q_{x,t}$ for $t = t_n + 1, \dots, t_n + T$;

Compute mortality indices for $t = t_n + 1, \dots, t_n + T$;

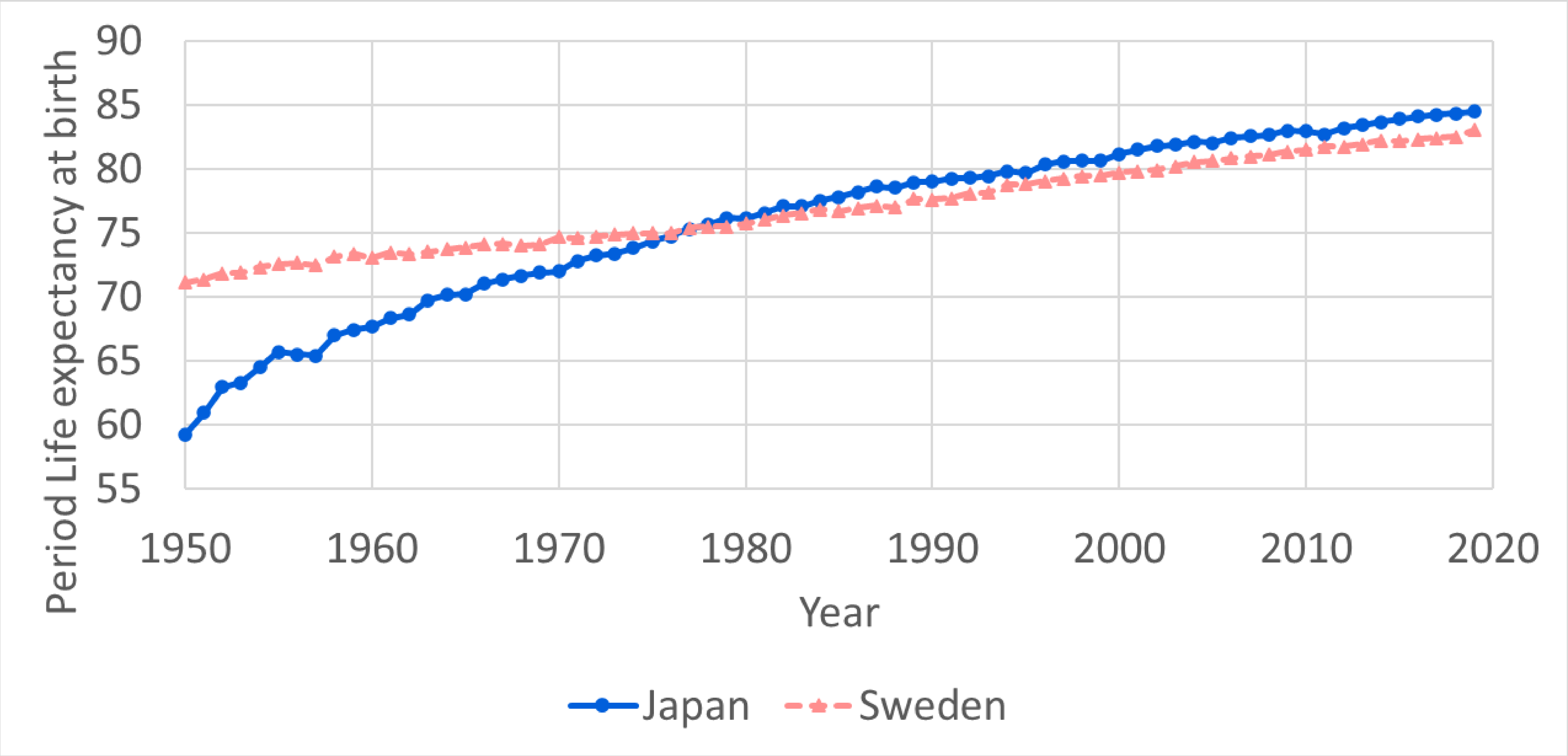
end

Forecast long-term trend of mortality improvement

- Long-term trend of mortality improvement: dictated by parameter μ in the model
- Steep decrease in mortality rates in Korea and Singapore since 1980's, but how will such trend evolve in future?
- Deceleration in Japan's mortality improvement after 1990's
- "Avant-garde" status in mortality improvement: overall level of mortality equals the minimum achieved at that time by any national population
- Example of countries "avant-garde" status: Sweden since 1960's, Japan since 1990's
- In simulation study: for Singapore, Japan and Korea, forecast with μ estimated from Japan's experience since 1990

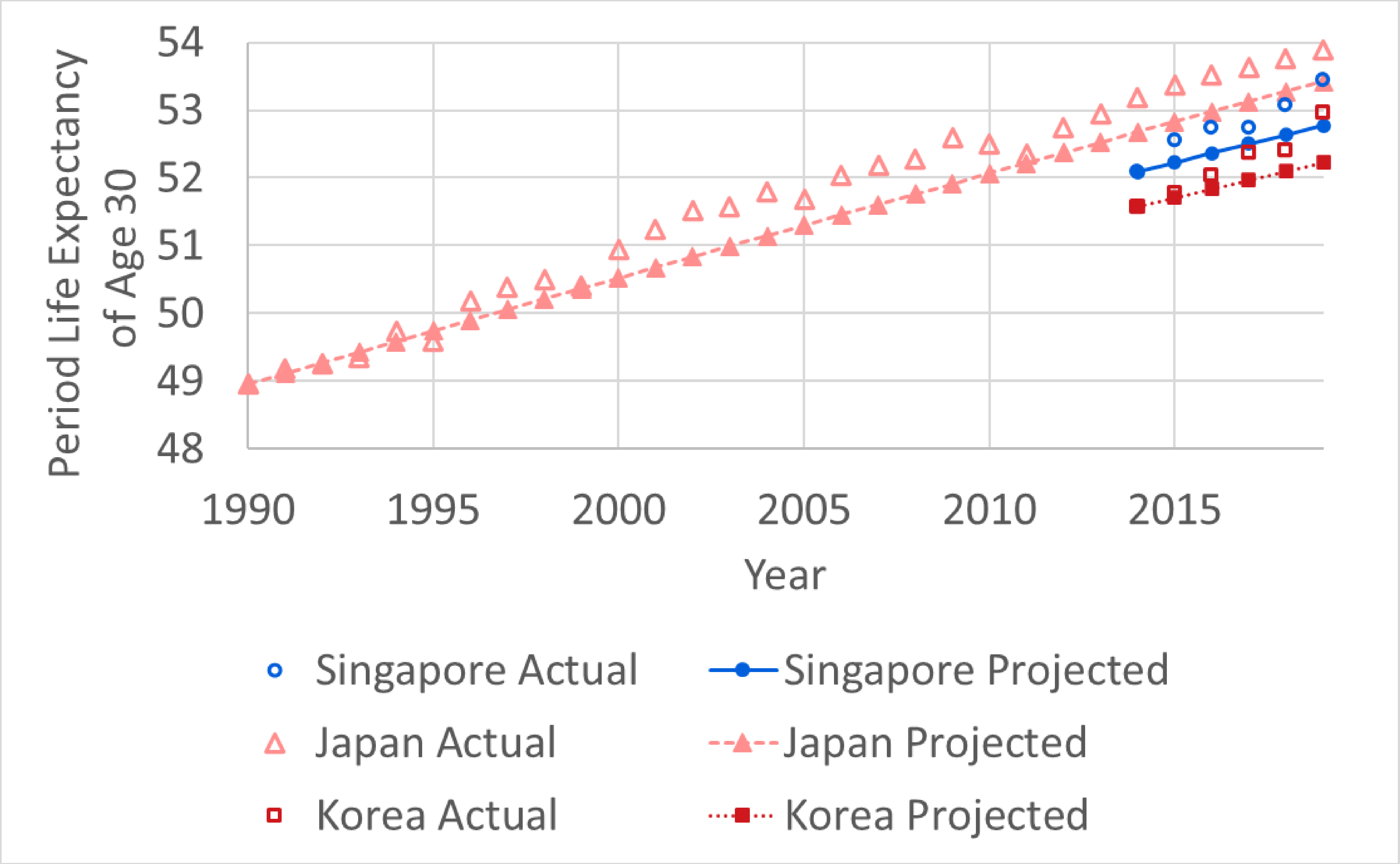
Forecast long-term trend of mortality improvement

Period life expectancy at birth



Forecast long-term trend of mortality improvement

Period life expectancy at age 30



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Appendix

Useful links

Living Lab report

- https://www.gaip.global/wp-content/uploads/2023/07/COVID-19-Mortality-Impact-in-Asia-.pdf

Tools: R codes and tables

- https://www.gaip.global/library-resource/tools-to-assess-mortality-impact-of-covid-19/